Science, Engineering and Education for Sustainability

SEES Discovery Articles National Science Foundation

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All Articles Written by Cheryl Lyn Dybas **Design and Layout by Sean Mark Watts**

Science, Engineering and Education for Sustainability (SEES)

To advance science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being.

Introduction: Planet at a Crossroads

NSF's Science, Engineering and Education for Sustainability (SEES) Investment Leads in New Directions

From Canada to Chile, from Kazakhstan to Kansas, we are witnessing a fast-changing planet. What will it look like in the years, decades and centuries to come?

How far, and in what ways, can Earth's systems be stressed before they undergo transitions to new states--with unforeseen consequences?

For most of its history, Earth experienced vast alterations in response to natural, planetary variations. Humans, however, are now emerging as the dominant agent of change.

Our world is at a crossroads.

With growing problems such as resource depletion, energy sustainability, environmental degradation and climate change, how can we protect the health of the planet and ensure fair access for all segments of society, while achieving widespread economic prosperity?

The answer is a sustainable world, one in which human needs are met without harm to the environment and without sacrificing the ability of future generations to meet their own needs.

To respond to this challenge, more information is needed about how the natural world, society and human alterations to the environment fit together.

Scientists, engineers and educators across NSF's SEES investment portfolio are looking at new ways of asking and answering questions about our sustainable future: where have we been, where are we going, and how do we best get there?

We must move beyond identifying issues and toward providing sound bases for the development of innovative solutions, as well as toward effective adaptation and mitigation strategies. It will take forming new partnerships and crossing disciplinary divides.

The NSF/SEES discovery articles that follow highlight SEES efforts in Dimensions of Biodiversity; Ocean Acidification; Water, Sustainability and Climate; Coupled Natural and Human Systems; Decadal and Regional Climate Prediction Using Earth System Models; and Research Coordination Networks. These projects address sustainability in the shadow of a huge—and growing--global footprint.

Ours.

Cheryl Lyn Dybas
NSF Science, Engineering and Education for Sustainability (SEES) Investment:
http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707

Earth Week: A Stream Is a Stream Is a Stream: Or Is It?

Scientists ford high-mountain waterways in North, South America to find out

16 April 2012

Scientists supported by NSF SEES use everything from microscopes to deep-sea submersibles in their research.

But how many need a machete?

During Earth Week--or any time of year--that's exactly what LeRoy Poff requires. Poff is an aquatic ecologist and evolutionary biologist at Colorado State University and an NSF SEES Dimensions of Biodiversity principal investigator.

Scientist LeRoy Poff samples aquatic insects along a vine-choked stream in Ecuador.

To characterize the lesser-known aspects of the diversity of life on Earth, NSF's decade-long Dimensions of Biodiversity campaign aims to transform, by 2020, how scientists describe and understand the scope and role of life on Earth.

The effort is funded by NSF's Directorate for Biological Sciences, Directorate for Geosciences and Office of Polar Programs.

"By establishing networks of interdisciplinary, globally-engaged scientists, Dimensions of Biodiversity will have a lasting effect on biodiversity science," says John Wingfield, NSF assistant director for Biological Sciences. "It has the potential to transform the way we conduct biological research in this arena."

The Dimensions of Biodiversity campaign is important, says Wingfield, because assessing the living diversity of Earth is not as straightforward as simply listing species.

Earth is rapidly losing species. It's happening faster than scientists can understand the roles these flora and fauna play and how they function.

With their disappearance comes lost opportunities to comprehend the history of life, to better predict the future of the living world and to make beneficial discoveries in the areas of food, fiber, fuel, pharmaceuticals and bio-inspired innovation.

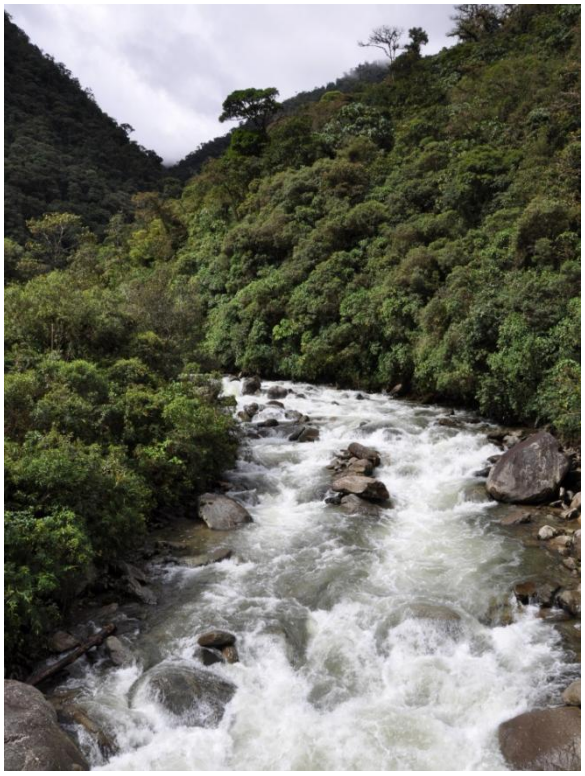
Poff and colleagues from Colorado State, Cornell University and the University of Nebraska are trying to change that.

They're studying how temperature variation and extreme weather such as floods and droughts affect life in temperate Colorado and tropical Ecuadorian streams.

Researchers Kayce Anderson and Brian Gill at a site beneath a waterfall along the Oyacachi.

The scientists are comparing how aquatic

insects and fish in small streams along the Colorado Front Range--which has a seasonally variable climate--and insects, fish and amphibians in streams in Ecuador, with its more stable climate, are faring at a time when Earth is heating up.



The Rio Santa Maria, a tributary of the Oyacachi River in Ecuador, runs fast after heavy rains.

"To get to our Colorado research sites," says Poff, "there's relatively easy access along mostly paved roads." But to reach streams in the cloud forest headwaters of the Amazon, he says, it takes a machete to bushwhack through tangled vines choking narrow waterways.

Poff and colleagues will identify new species in both locales by barcoding these species' DNA, as well as track their movements based on their tolerance of warming water and declining oxygen levels.

"We're trying to understand how animals will respond to climate change based on their evolutionary history in a particular climate zone," says Poff.

"To do that, we need to know their physiological responses to thermal and oxygen stress. This is one of the first studies to look at the sensitivity of species to both temperature and environmental variation such as floods and droughts."

The research team's hypothesis is that temperate species are likely to be less sensitive to climate change than those in the tropics.

Temperate streams are subject to large seasonal differences in temperature; the organisms that live in them occupy a wide range of elevations.

In the Colorado Rockies, for example, there's a big change between summer and winter temperatures in streams. That suggests, Poff believes, that species there could be somewhat tolerant of future climate warming.

In contrast, studying species diversity in the tropics, he says, is like taking apart the layers of a cake.

"Temperature doesn't vary seasonally at any given altitude," says Poff. "But as you move up in elevation you pass through layers of increasingly colder temperatures."

A project site in Colorado: a creek above Lake Isabella in the Indian Peaks Wilderness.

The omnipresent fog of the cloud forest in Ecuador's Oyacachi watershed.

He's trying to discover whether aquatic insects, fish and frogs are restricted to a narrow range of elevation and temperature--one layer of the cake.

"If they are--and that's coupled with a poor ability to disperse over land to find another small stream as temperatures warm--they could be more vulnerable to changes in climate," Poff says.

He plans to use a new understanding of species' sensitivity to climate change, and the ability of animals to move with changing conditions, as a basis for developing maps for policy-makers and others.

The maps will show where animals are most vulnerable to climate change in tropical and temperate streams.

"The knowledge being developed," says Tim Killeen, NSF assistant director for Geosciences, "will lead to improved, science-based decision-making about our common future."

To reach that goal, Poff is fording chutes from North to South America. His research takes not only microscopes and high-tech genetics labs.

It takes a machete.

Chris Funk, Rachel Harrington, Brian Gill and Dave Martin sampling in the Indian Peaks Wilderness.

Cry Me a River: Following a Watershed's Winding Path to Sustainability

NSF SEES "Water, Sustainability and Climate" award fosters new view of urban rivers, lakes

9 March 2012

A dot on a map of the United States, Cherokee Marsh in Wisconsin is central to the Yahara watershed.

Cherokee Marsh, it's called, this sunken enclave surrounded by cattails and bulrushes. The marsh is a mere dot on a map of the state of Wisconsin, but its importance reaches far beyond the wetland's edge.

The Yahara River flows through Cherokee Marsh, swirling through coontail, sago pondweed, glade mallow and other plant species along the Yahara watershed as it goes. Its next stop is the twins of Madison: Lakes Mendota and Monona.

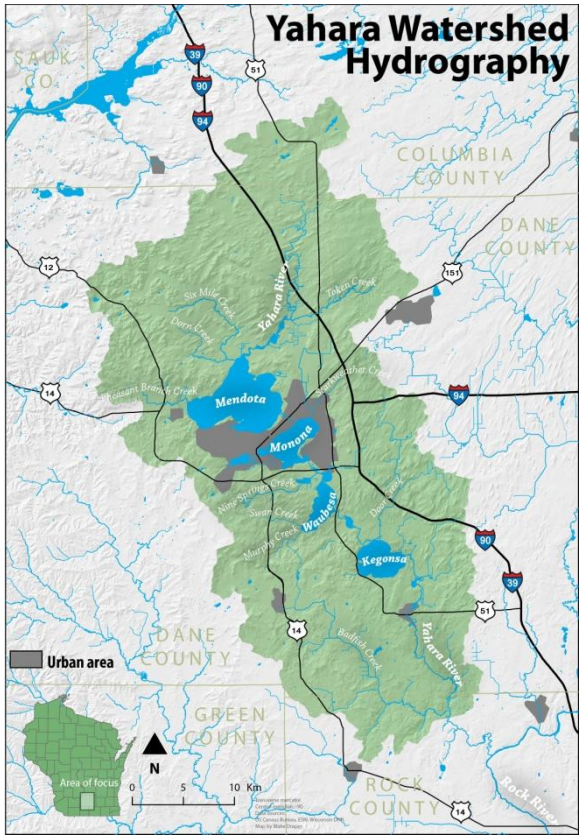
The river and its watershed provide Madison with critical "ecosystem services" such as water quality and flood protection, says Chris Kucharik, a scientist at the University of Wisconsin-Madison.

But the marsh, the twin lakes that lie downstream and the river that runs through them may be threatened by the effects of climate and land-use change.

The National Science Foundation (NSF) awarded Kucharik and colleagues a Water, Sustainability and Climate (WSC) grant to study how ecosystem services may be sustained in a regional watershed such as the Yahara, and how the watershed is affected as climate, land cover, urban areas and human demands on the environment change.

"The Yahara watershed," says Kucharik, "is a perfect example of water-related issues in the Upper Midwest."

How is the Yahara faring? Lakes Mendota and Monona may be the eyes that are the windows to its soul.



The Yahara River watershed extends through the city of Madison, Wis., and beyond.

Among the most urgent challenges facing the world today is how to ensure the adequate supply and quality of water, say scientists like Kucharik, especially in light of burgeoning human needs and climate variability and change.

Despite water's importance to life on Earth, major gaps exist in our understanding of water availability and quality, and of the effects of a changing climate and human activities on the planet's water system.

Aerial view of a rural farm surrounded by cornfields in the Yahara watershed.

NSF awarded 17 grants through the WSC program to better understand how Earth's water cycle works. NSF's Directorates for Geosciences; Biological Sciences; Social, Behavioral & Economic Sciences; and Engineering variously support WSC. The U.S. Department of Agriculture/National Institute of Food and Agriculture also currently support WSC.

The awards are for studies of the water system using observations at specific sites, in combination with models that allow for extrapolation to other regions and integration with different Earth processes.

"We need to determine how our 'built' water systems and our governance systems can be made more reliable, resilient and sustainable," says Tim Killeen, NSF assistant director for Geosciences.

"They must meet diverse and often conflicting needs," says Killeen, "such as consumption of water for energy generation, industrial and agricultural production, and other requirements."

Along with Kucharik, an agronomist and climatologist, scientists working on the NSF WSC Yahara watershed project are limnologist Steve Carpenter, ecohydrologist Steven Loheide, forest and wildlife ecologist Adena Rissman and landscape ecologist Monica Turner, all at the University of Wisconsin-Madison.

"Madison is a moderate-sized city that's growing quickly," says Kucharik. "It's one of the best examples of the issues surrounding urbanization. We have increasing water use due to a growing population; climate change happening, which is likely to foster extreme weather events; and it's in an agricultural watershed."

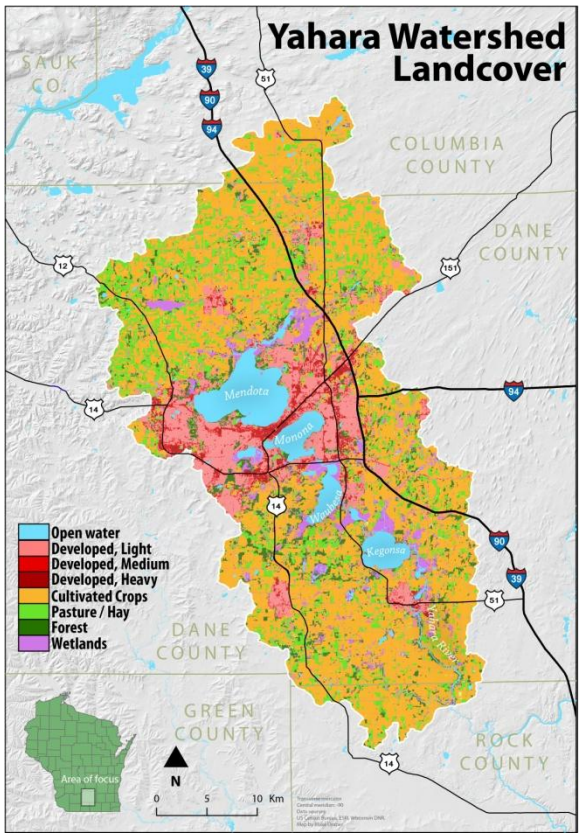
When you start putting all this together, Kucharik asks, what might it mean for the future of the Yahara watershed in terms of quality of life and the sustainability of the environment?

"With the interplay of agriculture, cities, industry and nature across the landscape, the contribution of direct-and-obvious, as well as indirect-and-subtle, interactions determines resilience to change," says Tom Torgersen, NSF lead program director for WSC. "This type of research is key to determining what needs to be done to ensure sustainability."

The Yahara watershed is largely agricultural--corn, soy and dairy products--but includes a densely populated urban area and remnant native vegetation.

A mix of urban areas, croplands, forests, pastures, wetlands and prairie makes for a

complex environment, especially when coupled with the region's water resources, says Kucharik.



The Yahara watershed encompasses marshes and lakes, prairies and forests.

Stresses on the ecosystem services of the Yahara watershed are typical of many agricultural landscapes.

Groundwater extraction, loss of wetlands, reduced water infiltration and increased runoff from impervious surfaces like roads alter the Yahara's hydrology and increase local and regional flood frequency.

Nitrates from agriculture contaminate groundwater, and phosphorus loads from non-point, diffuse runoff are greater than those prior to widespread farming.

Use of pesticides and fertilizers contributes to increased "flashiness" of runoff from heavy rainfall during storms, as well as to water quality issues in the area's lakes.

"More than 35 years of data for these lakes, assembled by NSF's North Temperate Lakes Long-Term Ecological Research site, have allowed us to develop models of lake response to changes in hydrology and in nutrient inputs," says Carpenter.

Climate change is making its presence in the Yahara watershed known. Since 1950, the number of extremely cold days has declined.

Many species of plants flower sooner in spring. "There's an early-season 'green-up' of some three to six days in the Madison area," says Kucharik.

In summer, water use by human residents of the watershed increases. The city acts as an urban heat island, making temperatures even higher.

"These factors all combine to challenge the sustainability of freshwater resources and other ecosystem services throughout the region," Kucharik says.

Initial findings by project scientists reveal that in 2011, dry conditions in mid-summer created

Algae cover the surface of Lake Mendota, likely the result of fertilizer flowing downstream.

potential water stresses for the Yahara watershed's natural and human systems.

In the long-term, however, the region has experienced higher water tables and a rising trend in precipitation amounts.

"Historical water table elevations are being reconstructed using a high-resolution model," says Kucharik. "We're combining the results with a review of historical aerial photos of water features in the upper part of the watershed."

This rising water table may be causing low-oxygen root conditions in some farm fields. Indices indicate a decrease in corn production, for example.

Project scientists monitor a network of 160 or more temperature-and-humidity sensors collecting continuous data across and beyond the urban landscape of Madison.

Combined with information from a mobile temperature-sensing unit, the results will provide a level of detail the researchers believe is unique in local climate and urban heat island studies.

"The results will advance our understanding of Earth's water resources," says Killeen, "and with it, our predictive capability not only for the availability of water, but for the future of life on our planet."

"We have the opportunity to change management practices while the Yahara watershed is still relatively healthy," says Kucharik. "Let's not wait until its mainstem river is only a trickle."

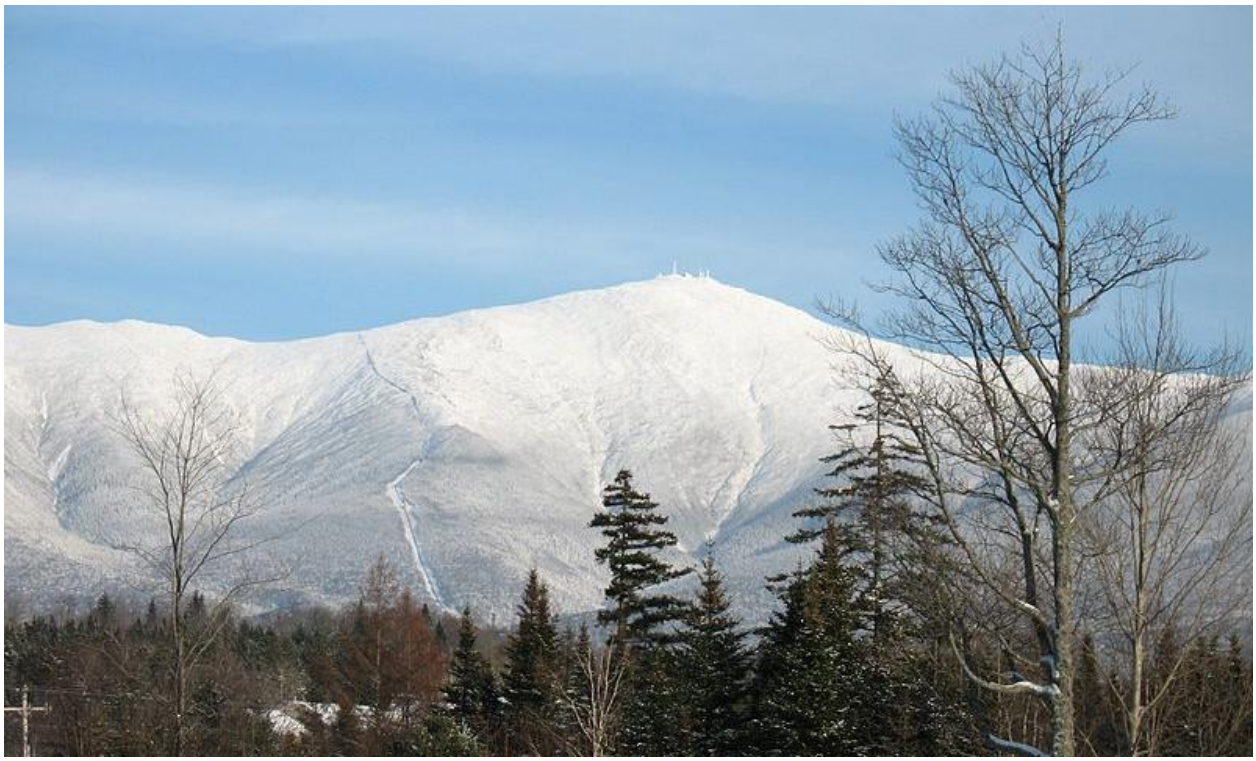
Or until the reeds of Cherokee Marsh have dried up, scattering the watershed's heart to the four winds.

Prairie fringes the Yahara River, which flows into Lakes Mendota and Monona.

The Snows of Mount Washington

Climate and environmental change in the U.S. northeast corridor

2 March 2012



Will Mount Washington, N.H., stay snow-covered in winter? Scientists are finding answers.

> *Kilimanjaro is a snow-covered mountain 19,710 feet high, and is said to be the highest mountain in Africa. Close to the western summit there is the dried and frozen carcass of a leopard. No one has explained what the leopard was seeking at that altitude.*
> - Ernest Hemingway, *The Snows of Kilimanjaro*

It's March, but a big snow has fallen in the U.S. Northeast for perhaps the first time this winter.

What's going on in traditional New England "snow towns" like Boston, Burlington and Brattleboro--and atop New Hampshire's famed Mount Washington, which is often snow-covered through July?

Is this seemingly snowless winter a blip on the radar screen, or a harbinger of things to come?

What will Earth's climate be like in a century, a decade or sooner? And what will it be like where you live, if you're in Massachusetts, Vermont or other northeastern states?

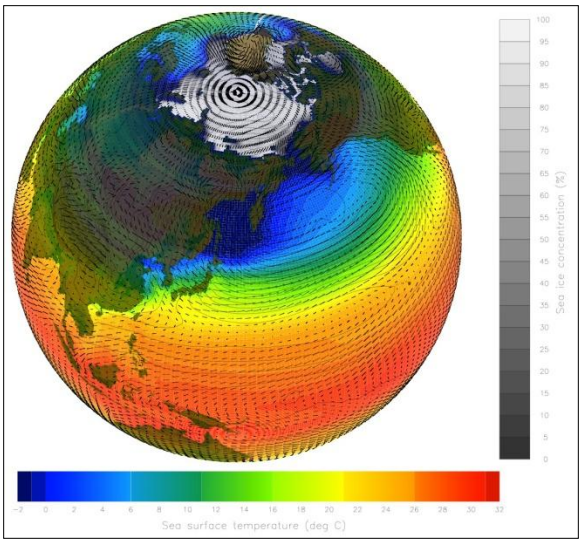
Or in Africa?

National Science Foundation (NSF)- funded scientists are working to find answers.

Toward that end, NSF recently awarded 29 grants to study the consequences of climate variability and change.

The grants were made through the interagency Decadal and Regional Climate Prediction Using Earth System Models (EaSM) program, co-funded by NSF, the U.S. Department of Agriculture and the U.S. Department of Energy.

"The EaSM projects will expand the limits of our understanding of Earth's climate system," says Tim Killeen, NSF assistant director for Geosciences.



Simulation of one month of 20th century climate, with the Community Climate System Model.

"They will lead to better ways of predicting climate change. The knowledge being developed will result in improved, science-based decision-making about our common future."

The consequences of climate variability and change are more immediate and profound than previously anticipated, scientists believe.

Prolonged droughts; increasing stresses on natural and managed ecosystems; loss of agricultural and forest productivity; degraded ocean and permafrost habitats; global sea-level rise and the rapid retreat of ice sheets and glaciers; and changes in ocean currents have shown that climate variability and change may have significant effects on decade and shorter time scales.

The effects, researchers have found, for humans and other animals, plants and physical systems such as the oceans may be far-reaching.

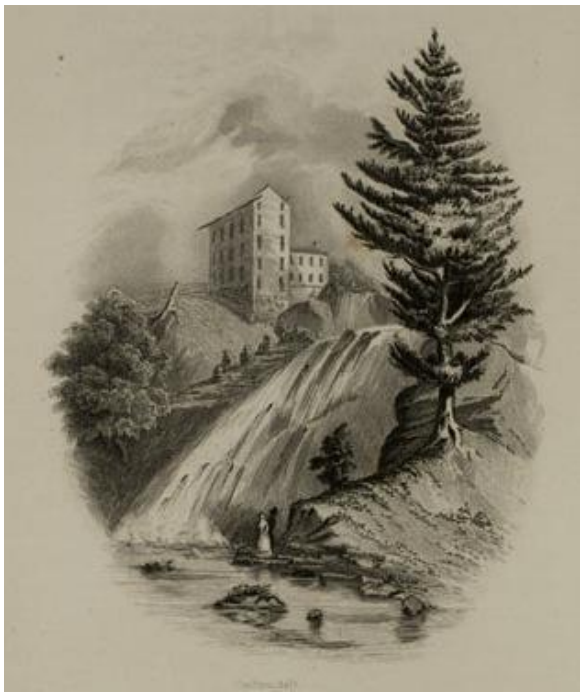
EaSM awardees such as scientist Charles J. Vorosmarty of the City University of New York and colleagues are studying the alterations taking place in the U.S. Northeast.

"This region reflects many of the changes across the nation's landscapes and watersheds," says Vorosmarty. "Because of its long history of development, it provides a unique lens to look at options for managing large-scale natural systems."

From early settlement to deforestation and land-clearing, to industrialization, urbanization and mega-city growth, and to post-industrialization, the region has been transformed.

"Such human actions will continue," says Vorosmarty, "and likely be more difficult to manage in a rapidly changing climate and environment.

"We will have major challenges trying to balance such needs as improving energy efficiency, maintaining water quality and deciding how best to manage the billions of dollars that will be needed for civil and private infrastructure."



Past is prologue? "Red Mill Fall (Opposite Albany)" by William Tolman Carlton, 1847-1849.

Because the atmosphere, land and aquatic systems, rivers and streams, and the ocean are closely linked through water and biogeochemical cycles, change to one has the potential for system-wide feedbacks and unintended consequences.

"Scientists' current ability to understand human-environment interactions on a regional basis--and across several decades--is limited," Vorosmarty says, "as are tools for environmental planners to formulate sound decisions."

The EaSM team is working to develop a Northeast Regional Earth System Model that improves the ability to forecast implications of planning decisions on the region's environment, energy use and economy through the 21st century.

Economic Sciences and its Office of Cyberinfrastructure and Office of Polar Programs.

"The research will provide new insights," says Blood, "into the complex links among human and ecological systems and critical Earth processes operating on decadal and regional scales."

The model is being used to test whether there are significant consequences of worldwide and nationwide human decisions on the northeastern region's environment.

"The American Beaver," by John James Audubon, in: The Quadrupeds of North America, 1854.

"The model will be the first to integrate the human causes of decadal climate change with land and aquatic ecosystems, and with the 'ecosystem services' they provide to all of us, as well as with socioeconomic effects and management and policy decisions," says Elizabeth Blood, program director in NSF's Biological Sciences Directorate, which supports Vorosmarty's award.

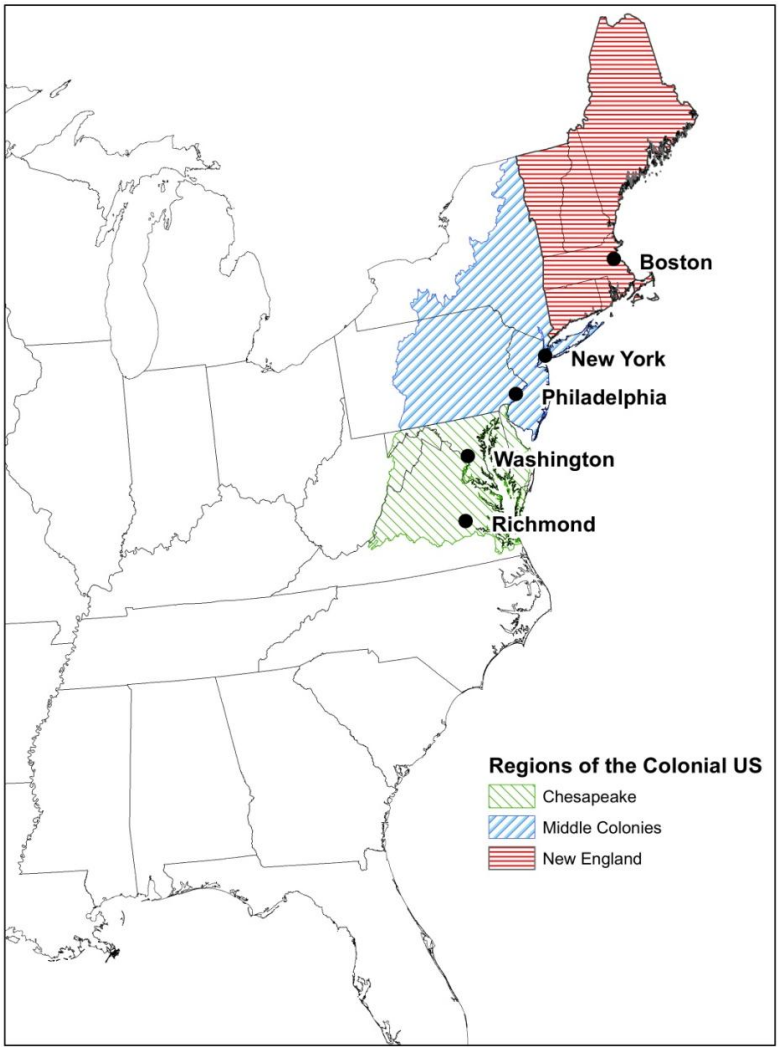
The EaSM grants are also funded by NSF's Directorates for Geosciences, Mathematical & Physical Sciences, Computer & Information Science & Engineering, and Social, Behavioral &

"We hope that our research will be a major step forward in understanding the state of large, interacting human and natural systems, with results that can be used to inform policy decisions," says Vorosmarty.

To look forward, however, one must first look back.

As a first step, the colonial hydrology of the northeastern U.S. has been reconstructed by Vorosmarty and other geoscientists, biological scientists and social scientists.

Their findings, which extend to the year 1600, are a new way of uncovering the past.



Map showing the region of study broken down into socio-cultural sub-regions.

Throughout American history, water resources have played an integral role in shaping patterns of human settlement and networks of biological and economic exchange.

The scientists divided their study area into three geographic and socio-political sub-regions: New England, the Middle Colonies and the Chesapeake.

They then looked at the ways in which variables such as soil, vegetation and climate combined with socio-political factors to influence each sub-region's hydrologic environment.

In New England, for example, close-knit religious communities with strong central governments concentrated their economic efforts on fur-trading and timber extraction.

The Chesapeake region, on the other hand, was settled largely by young, unskilled men who cleared trees and planted tobacco fencerow-to-fencerow. Their efforts caused extensive erosion, which dramatically altered rivers.

The Middle Colonies were characterized by diverse social, cultural and religious traditions, and by feudal-style estate agriculture.

These past activities need to be integrated into today's analyses of land-cover change and climate change, says Vorosmarty. "The key lesson is that the effect of decisions made long ago lasted for hundreds of years. The future will hold the same."

New information from the Northeast Regional Earth System Model will allow researchers like Vorosmarty to diagnose the health of the regional environment, including its climate.

"What direction that's heading," says Vorosmarty, "is a weathervane for us as well. If we want to change where it's pointing, the time is now."

Whether on New Hampshire's Mount Washington or Africa's Mount Kilimanjaro, whither the snows go, so, too, may we.

Boston's Copley Park during the blizzard of 2005; feet of snow blanketed the region.

Studying Nature's Rhythms: Soundscape Ecologists Spawn New Field

Listen to biophony, geophony, anthrophony: the 'music' of Planet Earth

6 February 2012

Soundscape: the landscape of 'nature's music' when a wolf howls in the forest.

Geophony. Biophony. Anthrophony.

Unfamiliar words. But they shouldn't be. We're surrounded by them morning, noon and night, say ecologist Bryan Pijanowski of Purdue University and colleagues.

The evening "singing" of frogs. Burbling brooks, breaking waves and the whistling wind. Planes, trains and automobiles.

Biophony is the music created by organisms like frogs and birds; geophony, the composition of non-biological sounds like wind, rain and thunder; and anthrophony, the conglomeration of noise from humans.

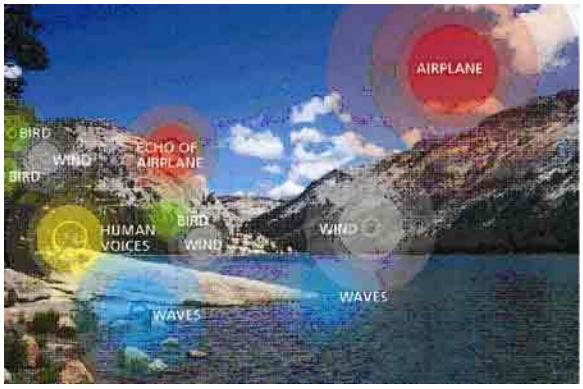
What they add up to is a cacophony--a mix of sounds made by the environment, and by people; a background to which most of us have become tone-deaf.

"Another word for it is 'soundscape,'" says Pijanowski.

He and colleagues are leading an effort to spawn a new field called soundscape ecology. It uses "nature's music" to understand the ecological characteristics of a landscape. It also reconnects people with Earth-sounds.

"Natural sound could be the 'canary in the coal mine,'" says Pijanowski. "Sound might be the critical first indicator of changes in climate and weather patterns, or the presence of pollution."

The dawn and dusk choruses of birds, for example, are characteristic of a certain location.



Sound surrounds us, in the sky, the land, the water.

If the intensity or frequency of these melodies change, "there's likely something causing it," says Pijanowski. "Ecologists have largely ignored the ways in which sound can help determine what's happening to an ecosystem."

To study soundscapes, Pijanowski and colleagues have received a grant from the National Science Foundation's (NSF) Dynamics of Coupled Natural and Human Systems (CNH)

See web-version for audio:

"Swamp chorus at night with rain and cicadas."
http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=123046&org=NSF

Program.

NSF CNH awardees work to provide a better understanding of natural processes and cycles, and of human behavior and decisions--as well as an understanding of how and where they intersect.

NSF's Directorates for Biological Sciences (BIO), Geosciences (GEO) and Social, Behavioral & Economic Sciences (SBE) support the CNH program.

CNH is part of NSF's Science, Engineering and Education for Sustainability (SEES) initiative.

"CNH highlights the need for scientists from different fields to work together and benefit from each other's perspectives to gain an understanding of the complex ways people interact with Earth's natural systems," says Tom Baerwald, CNH program director in SBE. "Findings from these projects will help individuals and groups address environmental problems more effectively."

"By bringing together researchers from a wide variety of academic fields," adds Sarah Ruth, CNH program director in GEO, "the projects are providing valuable new insights into the ways in which we, our environment, and the natural resources we rely on act as one interconnected system."

"CNH addresses societal challenges in the management of 'ecosystem services' and in adaptation to climate change," says Alan Tessier, CNH program director in BIO. "The soundscapes project is one such effort."

Since Rachel Carson's far-reaching 1962 book *Silent Spring*, the sounds of nature have been linked with environmental quality.

"Over increasingly large areas of the United States," wrote Carson in *Silent Spring*, "spring now comes unheralded by the return of the birds. The early mornings are strangely silent where once they were filled with the beauty of bird song."

Carson's observations turned out to be right. What began as her observation of sound--or its absence--ultimately led to the ban of DDT, the insecticide responsible for precipitous drops in numbers of bald eagles and their avian relatives.

The study of soundscapes can yield valuable information about very different landscapes, say Pijanowski and colleagues like Bernie Krause of Wild Sanctuary, Inc., in Glen Ellen, California, and Almo Farina of Urbino University in Italy.

Pijanowski has mapped soundscapes in wetlands and agricultural fields in Tippecanoe County, Indiana; near burbling streams and in high-wind chaparral in Sequoia National Park, California; and in the bird-song-filled forests of Italy and Costa Rica.

The ecosystem that surrounds the La Selva Biological Station in Costa Rica, for example, is home to more than 5,000 species of plants, 500 species of birds, three dozen frogs and kin and hundreds of species of insects.

Biophony is biological sound, for example, from frogs, birds, other animals that chirp or sing.

All these animals--including poison dart frogs, cicadas, great green macaws and howler monkeys--contribute to the La Selva biophony.

"Geophony is a hallmark of this landscape, too, with strong winds moving through trees, raging rivers audible from far away, and intense tropical rain showers that fill the 'acoustic spaces,'" says Pijanowski.

Acoustic spaces are equally "noisy" in the beech forests of Italy's Apennine National Park. There Pijanowski and other scientists collected three-hour recordings from 6 a.m. to 9 a.m. each day.

Data from the acoustic recorders were used to

construct "soundtopes"--three-dimensional maps of acoustics plotted across the landscape.

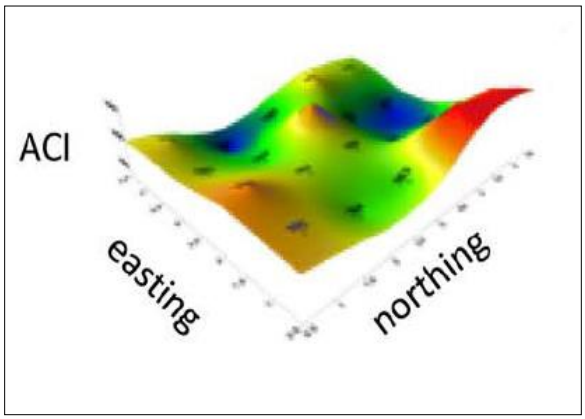
The daily maps show that large seasonal changes happen in this beech forest. "We

Geophony: the composition made by wind, rain, thunder, crashing waves, bubbling brooks.

anticipated that the maps would be similar," says Pijanowski. "But that wasn't the case."

Recordings like those made in Apennine National Park will become tomorrow's "acoustic fossils," says Pijanowski, "possibly preserving the only evidence we have of ecosystems that may vanish in the future."

Soundscapes, he believes, represent the heritage of our planet's acoustic biodiversity and reflect Earth's assemblages of organisms.



A "soundtope" of the biophony near Tuscany, Italy, during a geophony of falling rain.

"Natural sounds are an auditory link with our environment, one we need. Society's growing 'nature deficit disorder' is likely to increase as we replace these sounds with the din made by humans."

Almost 50 years ago, Rachel Carson highlighted the dangers of pesticides and their potential threats to wildlife, and to us.

A half-century later, "the unintended silencing of organisms by human activities is an indication of our continued effect on the planet's ecosystems," says Pijanowski.

Through soundscape ecology, he hopes to record and study Earth-music--while there's still time.

While frogs yet sing, waves break, and the wind whistles through the forest.

Biodiversity of Earth's Richest Plant Kingdom Under Fire

In response to climate change, will a postage-sized-domain move uphill – and ultimately out of room?

27 January 2012

A Cape sugarbird rests on a protea flower in Kirstenbosch Gardens, South Africa.

Climate change is on your porch and in your backyard and living room--anywhere you bedeck with flowering plants.

Global warming affects favorite flowers of garden and vase around the world, including the proteas and the pelargoniums native to South Africa.

Pelargoniums are wild ancestors of common geraniums. Proteas, with their vase-shaped bracts surrounding pencil-thin flowers, look like brightly-colored sea anemones.

During the Northern Hemisphere's winter, summer comes to South Africa and proteas and pelargoniums bloom in riotous color. On steep, rocky slopes, their red and pink flowers dot the hillsides.

"As one of the most diverse plant groups in South Africa, the pelargoniums have a variety well beyond what's available at even the largest U.S. nursery," says Carl Schlichting, an ecologist and evolutionary biologist at the University of Connecticut who specializes in these flowering plants.

But pelargoniums and proteas such as the king protea, which measures 12 inches across and is the national flower of South Africa, are under fire. Some will become extinct. Some already have.

Biologist Ross Turner on a protea-laden ridge on the Cape of Good Hope in South Africa.

***Protea obtusifolia*, it's called. It and other similar protea species live in South Africa.**

In a region where average temperatures have significantly warmed over the past 30 years, South Africa's--if not the world's--most unusual flowers are besieged.

In response, they're moving uphill to cooler or wetter spots. When will they run out of room? No one knows for sure. But time is of the essence in learning about this ecosystem, says Schlichting.

Despite centuries of discovery, most of the planet's biodiversity remains unknown. The scale of that unrecognized biodiversity is a vital question, scientists believe, given its rapid and permanent loss around the globe.

To respond to the need for more knowledge and a better understanding of Earth's biodiversity, the National Science Foundation (NSF) recently awarded 25 grants in its Dimensions of Biodiversity campaign.

The effort is part of NSF's Science, Engineering and Education for Sustainability (SEES) initiative.

Schlichting and colleagues comprise one of the research teams funded.

"By establishing networks of interdisciplinary, globally-engaged scientists, Dimensions of Biodiversity will have a lasting effect on biodiversity science," says John Wingfield, NSF assistant director for Biological Sciences. "It has the potential to transform the way we conduct biological research in this arena."

The Dimensions of Biodiversity campaign is important, believes Wingfield, because assessing the living diversity of Earth is not as straightforward as simply listing species.

The campaign is transforming how the role and scope of life on Earth is described and understood, he says.

It promotes novel, integrated approaches to identifying and comprehending the evolutionary and ecological significance of biodiversity in today's changing environment and in the geologic past.

"Dimensions of Biodiversity is accelerating the pace of biodiversity research and discovery, and it enables scientists to think at grand scales," says Joann Roskoski, NSF deputy assistant director for Biological Sciences.

Pelargoniums, or geraniums, thrive in South Africa's Baviaanskloof Nature Reserve.

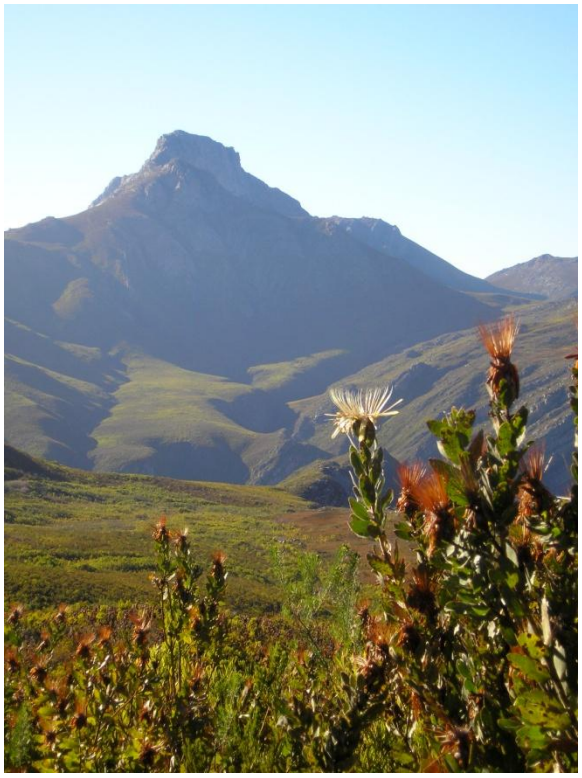
"Collaborative teams have formed to tackle some of the big questions using novel and integrative techniques," she says. "Taxonomists are talking to geneticists; geneticists to ecologists; and ecologists to taxonomists. This is not business as usual."

With the loss of Earth's biodiversity, biologists have found, links in the web of life that provide ecosystem services are being lost; an understanding of the history and future of the living world is being forfeited; and beneficial discoveries in the domains of food, fiber, fuel, pharmaceuticals and bio-inspired innovation are being eliminated.

That reality has stimulated the NSF awards, co-funded by NSF's Directorates for Biological Sciences and Geosciences.

"Dimensions may accomplish in 10 years what, with a piecemeal approach, would have taken 50 years--a half-century we can no longer wait," says Roskoski.

Proteas are the keystone species of South Africa's Cape Floral Kingdom, the smallest but, biologists say, the richest of Earth's six plant kingdoms.



South Africa's Cape Floristic Region is one of the world's plant biodiversity hotspots.

The Cape Floral Kingdom is the size of a postage stamp, comparatively speaking. It has the highest plant biodiversity, however, of anywhere on the planet.

About 9,000 plant species, 70 percent of which live nowhere else, are found there in what's called the fynbos ecosystem. Just to the north lies another, yet more diverse, desert-like ecosystem, the succulent karoo.

Near South Africa's Cape of Good Hope, leathery-leaved fynbos plants cover the mountains, valleys and coastal plains. Proteas and pelargoniums thrive despite nutrient-poor soils and high winds.

Schlichting's research focuses on how proteas and pelargoniums have diversified over the last 15 million years during periods of climate change in southern Africa.

"Contemporary climate change will drive responses at all levels of biodiversity, from the traits of individuals to distributions of species and biomes," says Schlichting.

"Our team hopes to combine an understanding of past evolutionary patterns with an assessment of modern diversity to make predictions about the future of plant communities."

Some pelargonium plants, for example, may be drought-avoiders, while others are drought-tolerators. Schlichting is discovering which ones are which.

These traits may be linked with the environment, he and others have found, and may indicate patterns of local adaptation.

"This study looks at one of the most diverse floras of the world," says Sam Scheiner, program director in NSF's Division of Environmental Biology, "and connects plant physiology with the evolutionary processes driving diversification. It is one of the most comprehensive views of this process, and promises to greatly expand our knowledge."

As Earth's climate warms, species like proteas

and pelargoniums will try to keep pace by adapting to new conditions or by moving to their preferred temperature and rainfall ranges.

Protea seeds, for example, are carried on the wind to new locations. Those that become rooted in cooler or wetter areas will survive.

"We may not have much time to understand why there is such a rich diversity of pelargoniums and proteas," says Cynthia Jones, a University of Connecticut scientist working on the project, "before they begin to disappear."

From porches, backyards and living rooms. And from fynbos and succulent karoo.

See web-version for video:

"Time-lapse video of scientists conducting surveys in South Africa to track biodiversity changes."
http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=122938&org=NSF

A large protea flower in Franschhoek Pass, South Africa.

Trouble in Paradise: Ocean Acidification This Way Comes

Sustainability of tropical corals in question, but some species developing survival mechanisms.

4 January 2012

Double, double toil and trouble;
Fire burn, and caldron bubble.
- Shakespeare, *Macbeth*

Mo'orea, it's called--this island in French Polynesia that's been dubbed the most beautiful isle in the world.

Here Tahitian breezes dance across crystal blue waters. Beneath the tropical seas lies a necklace of coral reefs that encircles Mo'orea like a string of brightly colored jewels.

Extensive reefs of a coral named *Porites* and other species form atolls, or reefs that ring Mo'orea's lagoons.

Porites are colonial corals, also known as Scleractinians, found in shallow tropical waters throughout the Indo-Pacific and Caribbean regions.

Think tropical reef and your mind's eye is likely seeing *Porites*.

These corals and other calcifying marine life, such as coralline algae, are also the world's primary reef-builders. And therein lies the trouble.

The seas in which these calcifying species dwell are turning acidic, their pH slowly dropping as Earth's oceans acidify in response to increased carbon dioxide in the atmosphere.

As atmospheric carbon rises in response to human-caused carbon dioxide emissions, carbon in the ocean goes up in tandem.

Marine life that depends on calcium carbonate can no longer form shells or, in the case of coral reefs, skeletons. Such marine life is found in waters that are more basic with a higher pH rather than a lower pH, which is more acidic.

Porites reefs, say scientists Peter Edmunds and Robert Carpenter of California State University at Northridge, are among the most sensitive of all corals.

Carpenter and Edmunds are two of the lead scientists at the National Science Foundation's (NSF) Mo'orea Coral Reef Long-Term Ecological Research (LTER) site, one of 26 such LTER sites around the globe.

Something wicked this way comes: ocean acidification arrives in paradises like Mo'orea.

Mo'orea is the only coral reef site in NSF's LTER network. It is funded by NSF's Divisions of Ocean Sciences and Environmental Biology.

To study the effects of ocean acidification on corals and other calcifying organisms, the Mo'orea biologists have been awarded an NSF SEES Ocean Acidification grant.

Beautiful coral reefs that ring the island of Mo'orea are affected by acidifying ocean waters.

We need to understand the chemistry of ocean acidification and its interplay with other marine processes--while Earth's seas are still hospitable to life as we know it, according to David Garrison, director of NSF's Biological Oceanography Program.

Carpenter and Edmunds hope to learn how fast--and the specific mechanisms by which--ocean acidification is affecting Mo'orea's corals and calcified algae, before the island's pristine reefs join dead and dying corals lining tropical coastlines around the world.

"Is there a way of sustaining healthy coral reefs when our oceans are acidifying?" asks Edmunds.

"Marine animals and plants from pteropods--delicate, butterfly-like plankton--to hard corals and coralline algae are affected by ocean acidification, as are the microbes that fuel ocean productivity and influence the chemical functioning of seawater.

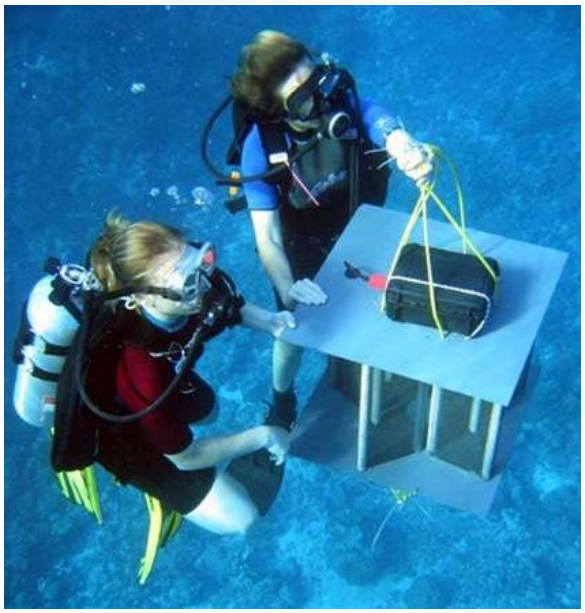
"Corals like *Porites*, with their extensive distribution in tropical waters, may be ocean 'canaries in the coal mine.'"

At the current rate, he and Carpenter believe, coral reefs could disappear by the turn of the

Marine scientists study how Mo'orea's corals and other species respond to more acid seas.

See web-version for video:

"Marine scientist Peter Edmunds talks about the worldwide importance of coral reefs, and how ocean acidification threatens these fragile ecosystems."
http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=122642&org=NSF



Underwater office: researchers obtain information on Moorea's coral reefs.

next century.

"The loss of biodiversity," says Carpenter, "would be devastating to the world's oceans--and to all of us. Tourism and fishing, in fact, entire economies, depend on coral reefs."

The scientists' recent findings are cause for hope, however. *Porites*, it turns out, may be developing an ability to counteract the effects of ocean acidification.

When Edmunds exposed *Porites* to different water temperatures and pH levels, and to plankton called brine shrimp as a food source, he found that increasing the amount of plankton in the coral's diet reduced the effects of ocean acidification.

The results are published in a recent issue of the journal *Limnology & Oceanography*.

"It's an intriguing mechanism," says Edmunds. "As seawater became more acidic, the corals continued to deposit calcium carbonate [new hard skeleton]. Although ocean acidification reduced the overall ability of coral tissue to calcify, the corals responded to more food by adding more tissue."

Edmunds thinks that the extra plankton food may allow the coral to "bulk up," thereby changing its internal structure and increasing its ability to manufacture skeleton even in acidifying waters.

"It's a surprising finding that corals can mitigate the effects of ocean acidification," says Garrison. "It will be important to uncover the specific mechanism, and to establish whether other species have this ability."

And whether, says Edmunds, it might allow *Porites* to survive in the more acid oceans of the future.

Edmunds and Carpenter found that the response of tropical reefs to ocean acidification may be species-specific, with some species of corals and coralline algae affected more than others.

They've also discovered that more acid oceans may lead to changes in patterns of biodiversity in a high-carbon dioxide world.

If the tropical seas cauldron continues to bubble with waters turning to acid, the scientists say, it will indeed lead to double, double toil and trouble--for the most beautiful island in the world, and for coral reefs around the globe.

Ultimately, it will affect the sustainability of life on a planet that--made up of 70 percent oceans--might better be called Water than Earth.

Moorea's corals form the backbone of a reef ecosystem that supports many other creatures.

Can Marcellus Shale Gas Development and Healthy Waterways Sustainably Coexist?

NSF Sustainability Research Coordination Network is Providing Answers

9 December 2011

Hundreds of streams and rivers large and small flow through the Marcellus Shale Formation

Amity, Pennsylvania. Epicenter of the natural gas-containing geological formation known as the Marcellus Shale.

Amity lies in Washington County near Anawanna, Pa. Once, Native Americans lived there. They named it Anawanna, or "the path of the water," in recognition of its many rivers and streams.

Today the Native American Anawanna is but a whisper in tales of the past, but the path of the water for which it's named is making headlines.

The Marcellus Shale Formation underlies some 95,000 square miles of land, from upstate New York in the north to Virginia in the south to Ohio in the west.

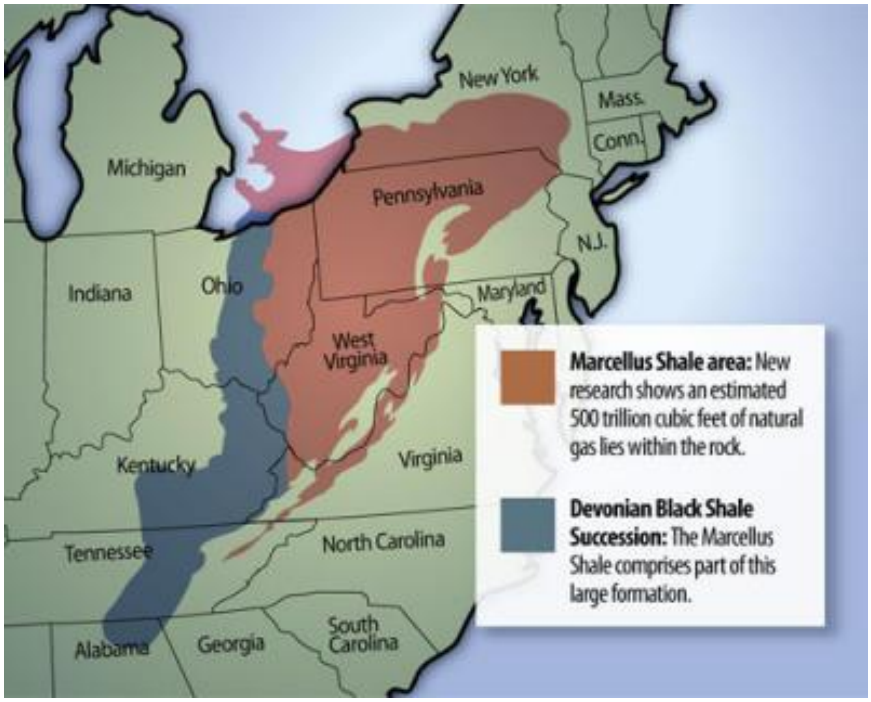
The bull's-eye, however, is under Pennsylvania in places like Amity. There the gas-bearing thickness of the shale reaches 350 feet; it thins to less than 50 feet in other areas.

The Marcellus Shale gas reservoir may contain nearly 500 trillion cubic feet of technically-recoverable gas. At current use rates, that volume could meet the U.S. demand for natural gas for more than 20 years.

The shale's proximity to the heavily populated mid-Atlantic and Northeast makes its development economically advantageous. Already, more than 4,000 shale gas wells have been drilled in Pennsylvania.

But the Marcellus Shale has a bête noire. With such rapid development, gas exploitation is creating environmental challenges for Pennsylvania--and beyond.

Retrieving the Marcellus Shale's gas requires a process known as hydraulic fracturing,



Marcellus Shale underlies a U.S. East Coast region from New York to Virginia.

hydrofracking or simply fracking.

Fracking involves the use of large quantities of water, three to eight million gallons per well, mixed with additives, to break down the rocks and free up the gas. Some 10 to as much as 40 percent of this fluid returns to the surface as "flowback water" as the gas flows into a wellhead.

Marcellus Shale natural gas drilling is proceeding apace in Pennsylvania.

Once a well is in production and connected to a pipeline, it generates what's known as produced water. "Flowback and produced water," says Susan Brantley, a geoscientist at Penn State University, "contain fluid that was injected from surface reservoirs--and 'formation water' that was in the shale before drilling."

Enter the bête noire.

These flowback fluids carry high concentrations of salts, and of metals, radionuclides and methane. "Such chemicals," says Brantley, "can affect surface and groundwater quality if released to the environment without adequate treatment."

A temporary freshwater impoundment to be used for fracking, or hydraulic fracturing.

The rapid pace of Marcellus Shale drilling has outstripped Pennsylvania's ability to document pre-drilling water quality, even with some 580 organizations focused on monitoring the state's watersheds. More than 300 are community-based groups that take part in volunteer stream monitoring.

Pennsylvania has more miles of stream per unit land area than any other state in the United States. "It's overwhelming to keep track of," says Brantley. "These community organizations have identified a need for scientific and technical assistance to carry out accurate stream assessments."

Working through the National Science Foundation's (NSF) Susquehanna Shale Hills Critical Zone Observatory (CZO), one of six such observatories in the continental U.S. and Puerto Rico, Brantley studies the "critical zone" where water, atmosphere, ecosystems and soils interact.

Now, with a grant from NSF's Science, Engineering and Education for Sustainability

(SEES) Research Coordination Networks (RCN) activity, Brantley is developing a Marcellus Shale Research Network.

The network will identify groups in Pennsylvania that are collecting water data in the Marcellus Shale region; create links among these organizations to meld the resulting data; and organize a water database through the NSF-funded Consortium of Universities for the Advancement of Hydrologic Sciences.

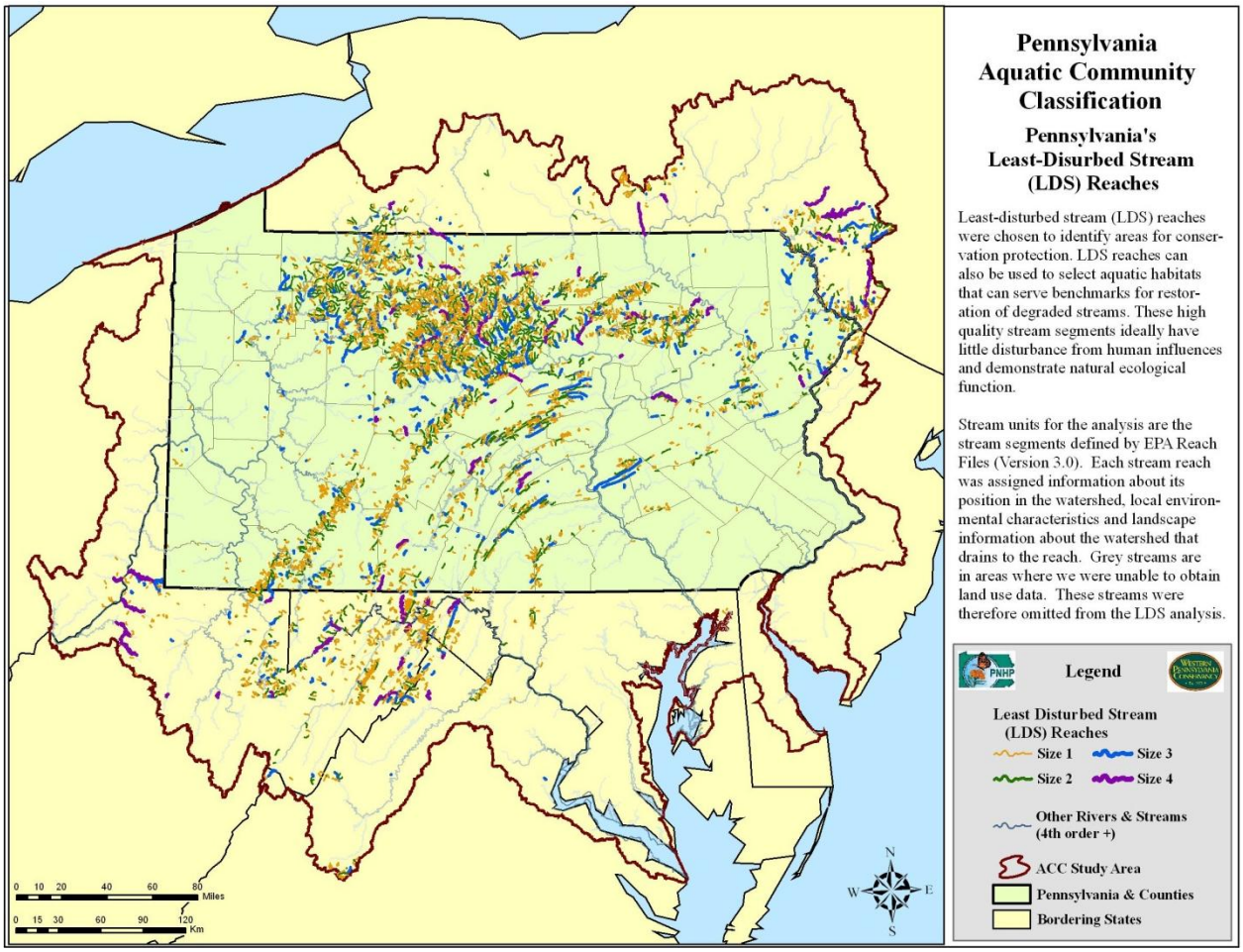
The database will be used to establish background concentrations of chemicals in streams and rivers, and ultimately to assess changes throughout the Marcellus Shale area.

The results, Brantley hopes, will help community groups evaluate hydrogeochemical data. The network will use geographic information systems that incorporate population and economic data to evaluate the potential for public health risks.

"An outcome of the NSF investment in the Susquehanna Shale Hills Critical Zone Observatory has been a better interpretation of the chemistry and flow of groundwater in shale," says Enriqueta Barrera, program director in NSF's Division of Earth Sciences, which funds the CZOs.

"The SEES-RCN project will use this information to assemble data collected by watershed associations, government agencies, and water scientists to further knowledge on the effect of hydrofracking on groundwater properties."

The Marcellus Shale RCN, says Brantley, "is designed to act as an 'honest broker' that collates datasets and teaches ways of synthesizing the data into useful knowledge.



Many of Pennsylvania's streams are unpolluted havens for aquatic life, including trout.

"The approach stresses that volunteer data acts as a 'canary in a coal mine' to inform agencies about when and where they need to intensify water quality monitoring."

Of particular concern are concentrations of salts such as barium and strontium, high in some discharges as a result of the mixing of gas drilling fluids with naturally-occurring barium-strontium-containing waters.

"Barium can cause gastrointestinal problems and muscular weakness," says Brantley, "when people are exposed to it at levels above the EPA drinking water standards, even for relatively short periods of time.

"Animals [such as cows, pigs, sheep] that drink barium-laced waters over longer periods sustain damage to kidneys and have decreases in body weight, and may die of the effects."

The waterways of Pennsylvania have recorded many of the important human activities in the history of the United States, Brantley says. "It's expected that they will record the development of the Marcellus Shale gas as well."

The rise and fall of coal mining is found in concentrations of dissolved sulfates in the state's rivers. Pennsylvania's air, water and soils retain the signature of the steel industry and of coal-burning over the last century in their low-level manganese contamination.

Documenting the effects of shale gas extraction, says Brantley, requires extensive water sampling and a database of long-term records.

In the past, monitoring sometimes has not begun until after effects were noticed. But times are changing. "In the future," says Brantley, "many monitoring networks of all kinds will need to include citizen scientists to keep costs down, and research scientists will need to learn to use such networks to the best outcome."

Can we have natural gas development and clean waterways?

The Marcellus Shale Research Network will provide much-needed answers, says Barrera. "Successfully developing new energy resources while maintaining healthy ecosystems," she says, "is the very heart of sustainability."

Geoscientist Susan Brantley of Penn State doing field work in the Marcellus Shale region.

Appendix I: Image Credits

Earth Week: A Stream Is a Stream Is a Stream: Or Is It?

Images 1–5: Chris Funk

Image 6: Kayce Anderson

Cry Me a River: Following a Watershed's Winding Path to Sustainability

1. City of Madison, Wisconsin
2. Blake Draper
3. Michael Forster Rothbart, UW-Madison
4. Blake Draper
5. UW-Madison
6. Sam Zipper

The Snows of Mount Washington

1. USFS
2. UCAR
3. Courtesy of the American Antiquarian Society
4. Courtesy of the American Antiquarian Society
5. Graphic by Jonathan M. Duncan
6. NOAA

Studying Nature's Rhythms: Soundscape Ecologists Spawn New Field

1. U.S. National Park Service
2. U.S. National Park Service
3. Luis Villanueva-Rivera
4. Bryan Pijanowski
5. Almo Farina, Urbino University

Biodiversity of Earth's Richest Plant Kingdom Under Fire

1. Adam Wilson, Univ. of Connecticut
2. Adam Wilson, Univ. of Connecticut
3. Kent Holsinger, Univ. of Connecticut
4. Cynthia Jones, Univ. of Connecticut
5. Jane E. Carlson
6. Adam Wilson, Univ. of Connecticut

Trouble in Paradise: Ocean Acidification This Way Comes

All Images: NSF Mo'orea Coral Reef LTER Site

Can Marcellus Shale Gas Development and Healthy Waterways Sustainably Coexist?

1. NPS
2. USGS
3. Chuck Anderson, Penn State
4. Chuck Anderson, Penn State
5. State of Pennsylvania
6. Penn State

Appendix II: SEES Programs

Participating Organizations:

- Directorate for Biological Sciences
- Directorate for Computer Information Science and Engineering
- Office of Cyberinfrastructure
- Directorate for Education and Human Resources
- Directorate for Engineering
- Directorate for Geosciences
- Directorate for Mathematical and Physical Sciences
- Office of Integrative Activities
- Office of International Science & Engineering
- Office of Polar Programs
- Directorate for Social, Behavioral and Economic Sciences

SEES-Related Activities and Opportunities:

Dimensions of Biodiversity (NSF12-528)

The Dimensions of Biodiversity campaign seeks to transform how we describe and understand the scope and role of life on Earth. The campaign promotes novel, integrated approaches to identify and understand the evolutionary and ecological significance of biodiversity amidst the changing environment of the present day and in the geologic past. This campaign takes a broad view of biodiversity, and currently focuses on the integration of genetic, taxonomic/phylogenetic, and functional dimensions of biodiversity. While this focus complements several core NSF programs, it differs by requiring that multiple dimensions of biodiversity be addressed simultaneously, in innovative or novel ways, to understand their synergistic roles in critical ecological and evolutionary processes.

Climate Change Education (CCE): Climate Change Education Partnership (CCEP) Program, Phase II (CCEP-II) (NSF12-523)

The CCEP Program seeks to establish a coordinated national network of regionally- or thematically-based partnerships devoted to increasing the adoption of effective, high quality educational programs and resources related to the science of climate change and its impacts. This solicitation is for proposals for (CCEP-II). CCEP-II awardees will receive up to 5 years of funding to support full-scale implementation of mature and robust strategic plans already developed by regional or thematic partnerships to improve climate change education activities at a significant scale and meet the goals of the CCE program.

Decadal and Regional Climate Prediction Using Earth System Models (EaSM) (NSF12-522)

This interdisciplinary grand challenge calls for the development of next-generation Earth System Models that include coupled and interactive representations of ecosystems, agricultural working lands and forests, urban environments, biogeochemistry, atmospheric chemistry, ocean and atmospheric currents, the water cycle, land ice, and human activities.

Ocean Acidification (OA) (NSF12-500)

The goal of this solicitation is to understand a) the geochemistry and biogeochemistry of ocean acidification; b) how ocean acidification interacts with biological and physical processes at the organismal level, and how such interactions impact the structure and function of ecosystems; and c) how the earth system history informs our understanding of the effects of ocean acidification on the present day and future ocean.

Sustainable Energy Pathways (SEP) (NSF11-590)

SEP calls for innovative, interdisciplinary basic research in SEES by teams of researchers for developing systems approaches to sustainable energy pathways based on a comprehensive understanding of the scientific, technical, environmental, economic, and societal issues. The SEP solicitation considers scalable approaches for sustainable energy conversion to useful forms, as well as its storage, transmission, distribution, and use.

Science, Engineering and Education for Sustainability Fellows (SEES Fellows) (NSF11-575)

Through SEES Fellows, NSF seeks to enable the discoveries needed to inform actions that lead to environmental, energy and societal sustainability while creating the necessary workforce to address these challenges.

Sustainability Research Networks (NSF11-574)

The goal of the Sustainability Research Networks (SRN) competition is to support the development and coalescence of entities to advance collaborative research that addresses questions and challenges in sustainability science, engineering, and education.

Partnerships for International Research and Education (PIRE) (NSF11-564)

The primary goal of PIRE is to support high quality projects in which advances in research and education could not occur without international collaboration. The FY 2012 PIRE competition will be focused exclusively on the NSF-wide SEES investment area.

Water, Sustainability and Climate (NSF11-551)

The goal of the WSC program is to enable new interdisciplinary paradigms in water research, which broadly integrate across the biological sciences, geosciences, engineering, and social sciences to address water systems in their entirety.

Research Coordination Networks (RCN) (NSF11-531)

The goal of the RCN program is to advance a field or create new directions in research or education. Groups of investigators will be supported to communicate and coordinate their research, training and educational activities across disciplinary, organizational, geographic and international boundaries. The program has a SEES track.

Dynamics of Coupled Natural and Human Systems (CNH) (NSF10-612)

This program promotes interdisciplinary analyses of relevant human and natural system processes and complex interactions among human and natural systems at diverse scales. The most recent revision of the solicitation included special emphasis on SEES related proposals.

Arctic SEES (ArcSEES) (NSF 12-553)

ArcSEES is a multi-year, interdisciplinary program which seeks both fundamental research that improves our ability to evaluate the sustainability of the Arctic human-environmental system as well as integrated efforts which will provide community-relevant sustainability pathways and engineering solutions. For this competition, interdisciplinary research will be focused in four thematic areas: the natural and living environment, the built environment, natural resource development, and governance.

If you would like to ***learn more*** *about SEES, visit our website* ***www.nsf.gov/sees****.*

If you would like to ***subscribe to the SEES listserv****, send an* ***email*** *to* ***listserv@listserv.nsf.gov*** *with the following text in the message: Subscribe SEES [Your Name].*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